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lectrical transport across singly and doubly-leposited layers of Ge in Al-Ge-Au sandwich tructures

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Abstract : Current-voltage measurements were carried out in vacuum on as-deposited vacuum-evaporated Al-Ge-Au samples fabricated on Al support discs at temperature between 123 and 300 K The Ge layers, of thicknesses ranging between 500 and 3500 Å, were deposited either in one, or in two steps. For the latter, the coating chamber was deliberately opened to air at room temperature for about 1 hour in between deposition of the component Ge layer. All the samples showed good ohmic properties The specific resistance (R_S) of the Al-Ge-Au samples increased as the thickness of the sandwiched Ge layer increased, but decreased as the temperature increased. Furthermore, the value of R_S for a sample with single step Ge layer was slightly lower than that of a two-step Ge layer of the same overall thickness. On the other hand, there was no significant change in the value of R_S for samples with the same thickness of composite Ge layers deposited in equal number of steps, irrespective of the thickness order of the component Ge layers We have proposed some energy band model to explain the results.

Keywords : Electrical transport, Al-Ge-Au samples, energy band model

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Introduction

nerous studies have been carried out on amorphous Ge (a-Ge) and their contacts with er materials. Some of these studies were aimed at elucidating on the current conduction chanisms of a-Ge over various temperature regimes [1–4]. Other studies were in some es interested in the nature of some contacts to the a-Ge films or layers, or in the role yed by such contacts *vis-a-vis* the a-Ge films or layers [5–15]. Some of the findings are vacuum evaporated Ge is amorphous in nature [11], that it exhibits p-type conduction and that carrier transport is by hopping between localized states at room temperature

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Part of the interest in amorphous semiconductors, including a-Ge, stems from the desire to obtain semiconductor substrates that are both cheap and relatively easy to produce. Such qualities are obviously attractive for semiconductor device fabrication. Now, it is well known that most deposition techniques produce only layers of limited thicknesses, usually a few micrometers in one single deposition. Therefore, in order to obtain layer thicknesses of several micrometres, multiple deposition becomes necessary. Such deposition would invariably require exposure of the deposited intermediate layers to air at some stage. There is therefore, need to study and compare the properties of multiply-deposited layers obtained by similar or different steps, and if possible, find suitable conditions for obtaining multiply-deposited layers whose properties are similar to those from single-step deposition. The present work is partly motivated by such considerations.

Also, previous work had shown that for planar structures of Al-Ge-Au, the Al/Ge junction is rectifying [15]. On the other hand, ohmic or nearly ohmic behaviour had been reported for Al/Ge junction in sandwich structures of Al-Ge-Au [11]. However, the ohmic behaviour of the latter structures has not been adequately explained. This is also partly the aim of our present studies

2. Experimental procedure

The aluminium support discs, on which the samples were latter fabricated, were first degreased by washing with soap solution and then rinsed in distilled, de-ionized water. Thereafter, the discs were etched in a solution containing H_3PO_4, HNO_3 and water in the ratio 17:1:2 [16] for 1 minute, and subsequently rinsed with distilled, de-ionized water and then blow-dried with dry gaseous nitrogen. The clean discs were then transferred to the chamber of an Edwards, model 306 coater and maintained at a vacuum of about 10^{-5} torr. First, a gold layer about 500 Å thick, was deposited by filament evaporation to cover the whole of one surface of each Al disc. A 500 Å thick, 1.2 cm diameter Ge layer was then evaporated onto some of the gold-covered discs. After deliberate exposure of the Ge covered discs to air for about 1 hour, another Ge layer, this time 1000 Å thick and still 1.2 cm diameter, was evaporated on top of some of the Au or Ge tops. Following the same procedure, a 1500 Å thick, and finally, a 2000 Å thick Ge layer, each of 1.2 cm diameter was deposited onto either Au tops, or Ge tops from previous coatings. Then, an Al layer 500 Å thick and 0.6 cm diameter, was deposited on top of the final coating of Ge, and so that the overall Ge layers of the samples were obtained either by one, or two-step depositions. All the evaporants were of 5N9 purity (Ventron, Germany). Thicknesses of the various evaporated layers were determined with an Edwards, model FTM3 Digital Film Thickness Monitor. The final sample configuration is shown in Figure 1, while the sample nomenclature and Ge deposition steps are as displayed in Table 1.

After fabrication, the samples were mounted, one at a time inside a liquid nitrogen varistat and maintained under a vacuum of about 10^{-4} torr. Good external electrical contact the samples were effected using In(Hg). Current-voltage data were taken at 123, 163, 13, 263 and 300 K. The current and voltage were measured, respectively, with a digital

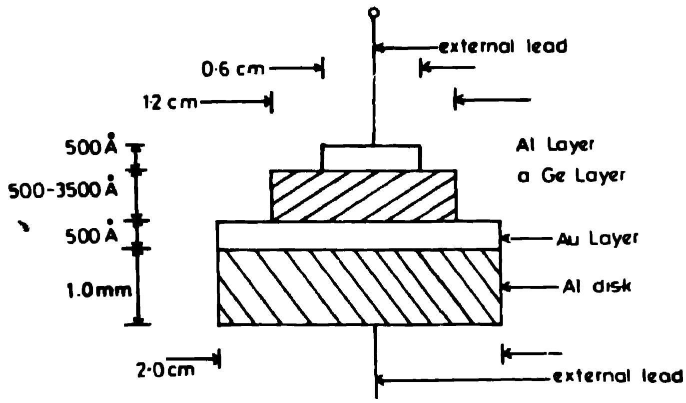


Figure 1. Cross-section of the Al-Ge-Au sandwich structure

Table 1. Sample names and thicknesses of both composite and component Ge layers
(The overall sample structure is Al-Ge-Au)

Sample name	Ge layer thickness (in Å) for		
	Step 1 coating	Step 2 coating	Steps 1 and 2 coatings
S1	500	–	500
S2	1000	–	1000
S3	1500	–	1500
S4	2000	–	2000
S5	500	1500	2000
S6	500	2000	2500
S7	1000	1500	2500
S8	1000	2000	3000
S9	1500	2000	3500

trometer (Keithley type 160 B) and digital millivoltmeter (Hewlett-Packard type 3465 om the current density (J)–voltage (V) plots, the specific resistance R_s was determined.

Results

samples displayed linear and symmetrical J–V characteristics in the voltage range +70 mV covered in these measurements. The upper limit of voltage was pegged at

70 mV due to the high current (over 200 mA/cm^2) flowing through the samples. Figure 2 shows the J–V characteristics at various temperatures between 123 and 300 K for one sample (S1) with Ge layer thickness of 500 Å deposited in one single step. The characteristics for the other samples were qualitatively similar. Figure 3 compares the J–V characteristics at various temperatures between 123 and 300 K of one sample (S4) with 2000 Å thick Ge layer which was deposited in one step, with those of another sample (S5),

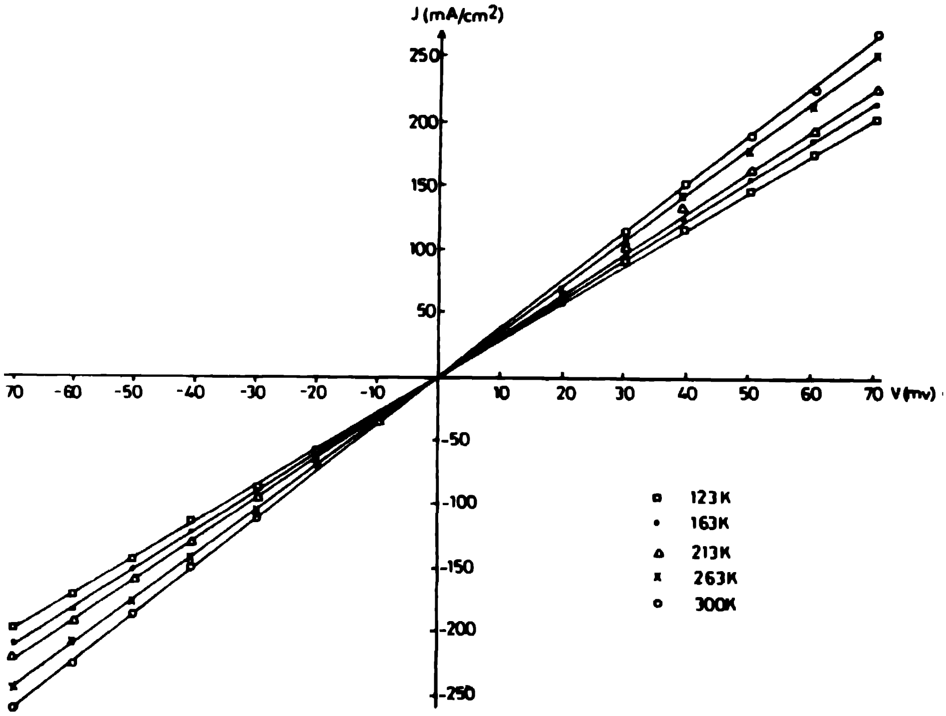


Figure 2. Current density (J)-voltage (V) plots for sample S1 at different temperatures.

also with 2000 Å Ge layer but which was this time deposited in two steps. The figure shows that the specific resistance R_s of sample S4 is slightly less than that of sample S5. On the other hand, Figure 4 compares the J–V plots at various temperatures between 123 and 300 K for one sample (S6) with 2500 Å thick Ge layer which was obtained by depositing 2000 Å Ge layer on top of 500 Å layer, and another sample (S7) also with 2500 Å thick Ge layer, but which was this time obtained by depositing 1500 Å thick Ge layer on top of 1000 Å layer. The figure shows that R_s of both samples (S6 and S7) are practically the same. R_s is plotted against temperature (T) for sample S4 in Figure 5. The plot is linear and shows that R_s decreases as T increases. The behaviour for the other samples is basically similar.

4. Discussion

The linearlity of the J–V characteristics of sandwich configurations of Al-Ge-Au samples, with thin Ge layers, indicate that the Al/Ge junctions are ohmic in the voltage range 0 to 70 mV covered in the present work. This behaviour agrees with the results of Hafiz *et al* [11] over the same voltage range. Our results however, contrast sharply with the rectifying

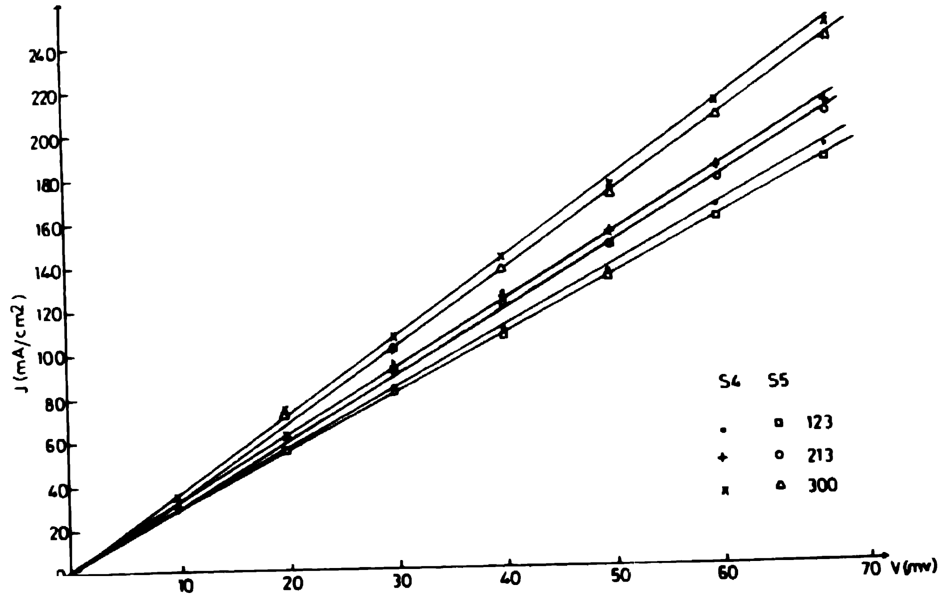


Figure 3. *J–V* plots for samples S4 and S5 at 3 temperatures.

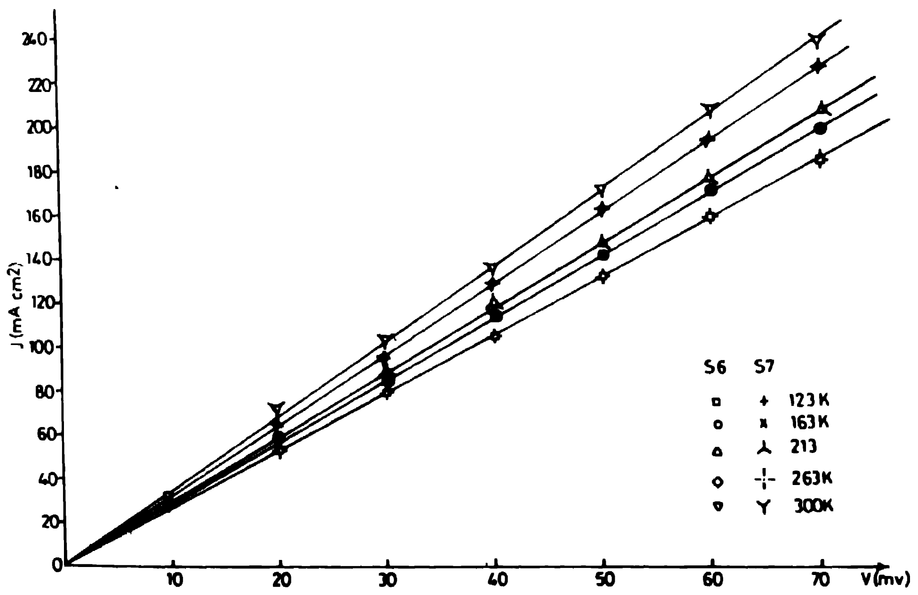


Figure 4. *J–V* plots for samples S6 and S7 at 5 different temperatures.

behaviour of Al/Ge junctions reported for planar structures of Al-Ge-Au samples deposited on plain glass support with relatively wide (700–20,000 μm) Ge layer [15,17]. We attribute the ohmic behaviour observed in the present work, to the thinness (≤ 0.35 μm) of the sandwich Ge layer which we note, is generally less than the width of a fully developed depletion layer on the Ge side of a metal/evaporated Ge junction. There has been report of depletion layer extending up to 0.33 μm from the metal junction into p-type Ge layer [18].

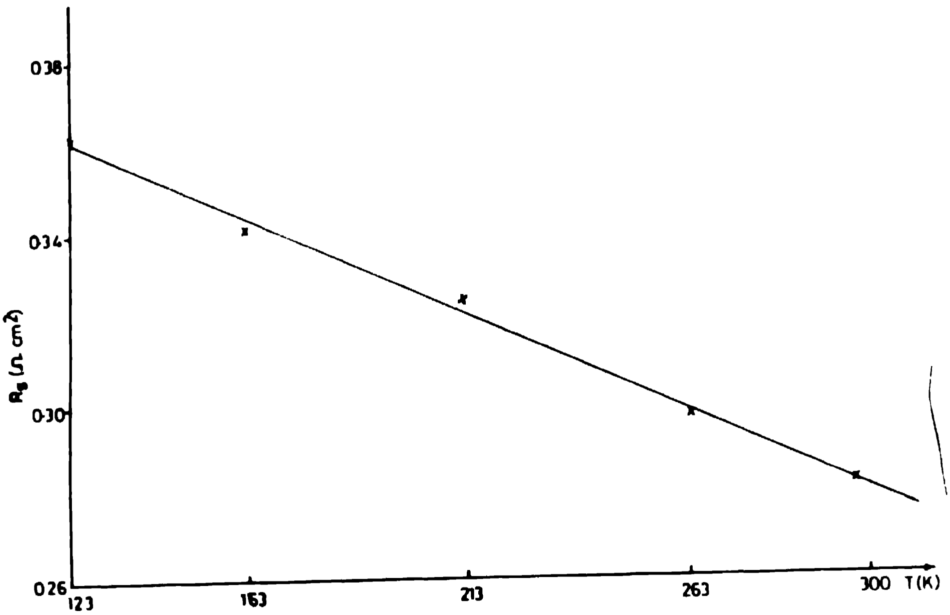
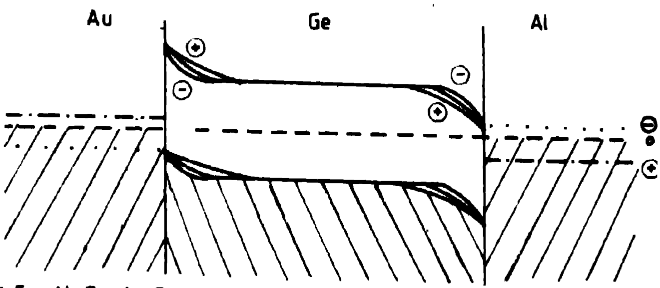


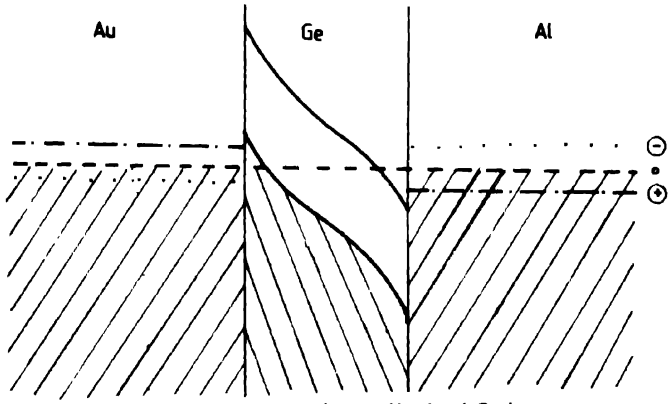
Figure 5. Plots of specific resistance (R_s) as a function of temperature (T) for sample S4.

We therefore expect the depletion layers from both the Au and Al side of the a-Ge layer tooverlap and ensure that the a-Ge layer is fully depleted. Thus, the Ge layers in our present measurements are thin enough for electrons from either metal to tunnel easily through in either direction depending on the polarity of the applied bias. The high current values (up to a few hundred milliamperes/cm^2) recorded even for small applied voltages (< 70 mV), and which showed no polarity dependence, seem to indicate that the current carriers are unipolar, and are in fact electrons which originate from the metal contacts only. In contrast, we note that, for Al-Ge-Au planar structures with relatively wide Ge layers, it has been reported that holes are the current carriers across the Ge layers [15].

Figure 6(a) is based on the energy band picture which was originally proposed by Oberafo *et al* [15] to explain current conduction in Al-Ge-Au planar structures with Ge layers sufficiently wide to sustain fully developed depletion regions near the metal contacts at both ends. In Figure 6(b), we present a band diagram suitable for structures with very thin Ge layers, that is, structures whose Ge layers are thinner than the width of fully developed depletion regions. The diagram shows that in equilibrium, there is a degenerate inversion layer on the Ge side of the Al / Ge junction and a degenerate accumulation layer on the Ge side of the Au/Ge junction. We see from this model that it is the electrons originating from either metal contact, and which are causing the Al/Ge and Au/Ge junctions to be respectively inverted and accumulated, that tunnel through the thin Ge layer.



(a) For Al-Ge-Au Planar structure with Ge layer.
(After Oberafo et al [15])



(b) For Al-Ge-Au sandwich structure with short Ge layer

Figure 6. Energy band model for Al-Ge-Au structure with the positions of the Fermi levels : (i) Under zero bias (- - - -) ; (ii) With positive bias on Al electrode (-. -. -. -) ; (iii) With negative bias on Al electrode (.) , ⊕ or ⊖ denotes positive or negative polarity, respectively, on the Al electrode

We see also from Figure 6(b) that as the temperature increases and for either polarity direction, the number of electrons excited above the Fermi level of either metal (Al or Au in the present case) should increase, thus making available additional carriers which can tunnel across the sandwiched Ge layers. Thus, the observed decrease in R_s as the temperature increased in our present measurements, is consistent with the above explanation.

The increase in the value of R_r as the thickness of the sandwiched Ge layer increased, is obviously due to the resulting increase in the distance across which the electrons have to tunnel. Such increase in the tunnelling distance is known to lower the tunnelling probability of the current carriers and hence the current [19].

The results also show that the value of R_s for samples with Ge layer deposited in one step is slightly lower than that with Ge layer deposited in two steps, with the latter samples subjected to an inter-step time break of about 1 hour during which the first Ge coating was deliberately exposed to air at room temperature. We believe that the additional resistance of the latter sample may be due to the natural growth of an oxide layer on the surface of the first Ge coating, following the break in vacuum after the first coating and the subsequent exposure to air at room temperature. The development of the oxide layer is akin to the reported automatic oxidation of etched Si surfaces by the oxygen in the air [20] and of thickness not exceeding 20 Å [21]. Such oxide layer in our present case, would sustain part of the applied voltage, thus reducing the voltage available and hence the band bending at the junctions of the Ge layer with the two metal contacts. The oxide layer would also increase the tunnelling distance. The overall effect would be to lower the current slightly as has been observed in our present work (Figure 3). For the same reason, samples with Ge layers deposited in equal number of steps would be expected to behave alike since they would both develop equal thickness of intervening oxide layer between any two component Ge layers, and experience equal voltage drop across each oxide layer. This agrees with our findings as depicted in Figure 4.

From the technological point of view, this multi-step deposition offers a quick and cheap method of fabricating amorphous semiconducting substrates of large thicknesses for use in semiconductor device fabrication. There is obviously, need to investigate the effect of annealing on the specific resitance of samples with multiply deposited Ge layers.

5. Conclusion

We have shown that the current transport through sandwich structures of Al-Ge-Au samples with thin Ge layers is both ohmic and unipolar in the temperature range 123 to 300 K. The current flow due to electrons from either metal contact, tunnelling across the intervening thin Ge layer, and the holes, which are the majority carriers in the sandwiched evaporated Ge layer, appear to play no significant role in the current flow. Furthermore, any break in vacuum with subsequent exposure to air at room temperature in between deposition of successive layers of Ge, results only in a slight increase in the specific resistance of the overall structure, probably due to oxide formation at such interfaces, and the specific resistance depends on both the number of interlacing oxide layers of the component Ge layers and the overall thickness of the composite Ge layer, but not on the thickness order of the component Ge layers.

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